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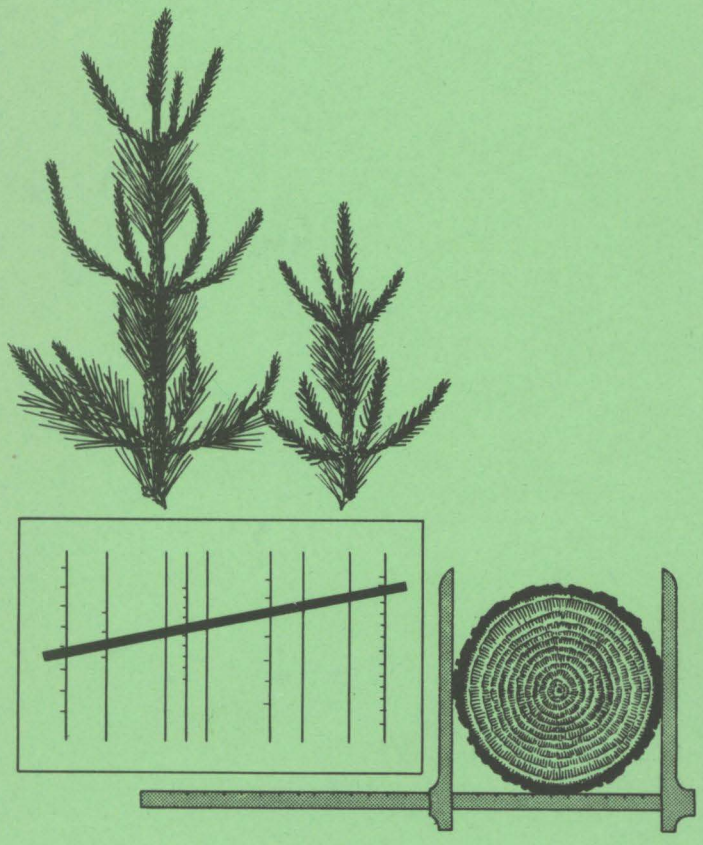
The Clements GROWTH PREDICTION CHARTS for residual stands of mixed conifers in California

By D. F. Roy



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GEORGE M. JEMISON, DIRECTOR

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THE CLEMENTS GROWTH PREDICTION CHARTS FOR RESIDUAL STANDS OF MIXED CONIFERS IN CALIFORNIA

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The rate of growth on cutover forest land is one of the major factors which must be considered to determine details of management policy. The rotation, the cutting cycle, and the size and amount of cut are dependent largely upon growth. In fact, complete management plans for sustained yield operations cannot exist without satisfactory knowledge of growth rates.

In 1939 Victor A. Clements developed a series of alinement charts to predict growth in residual stands of mixed conifers found in California. The charts were blueprinted and distributed at that time, but no descriptive material was published. We hope this report will fill the need for explaining the growth prediction charts and for acknowledging Clements' work.

The Data

Basic data covering periods of 18 to 20 years were obtained from permanent plots. These plots, aggregating 230.1 acres, are distributed from Shasta to Kern Counties in seven localities of the Sierra Nevada. Therefore, different geographical locations, site qualities, and species compositions were sampled. The stands varied in composition from almost pure ponderosa pine to a 5-species mixture of sugar pine, ponderosa pine, Douglas-fir, white fir, and incense-cedar, with gradations of 2, 3, and 4 species between. Site index ranged from 125 to 200 (2). 1/

Net growth of the stand was divided into two positive and one negative component: (a) growth of the residual stand (trees originally 11.6 inches in diameter at breast height and larger that lived throughout the period of observation), (b) ingrowth (board foot volume assigned to poles originally 3.6 to 11.5 inches d.b.h. when entering the 12 inch diameter class, plus subsequent growth), and (c) mortality or loss (original volume of residual trees 11.6 inches d.b.h. which died during the period of record).

Candidate variables were tested by multiple linear correlation to determine if they were good measures for variability of growth or mortality. Those which proved to be strongly correlated were then tested for culvilinear relations by the alinement chart method (1).

1/ Underlined numbers in parenthese refer to Literature Cited, p. 10.

Definition of Variables

The variables which were used in the growth and loss alinement charts are defined below. They are listed, with their key letters, in the order they appear in the charts. All variables refer to the residual stand condition immediately after logging.

Growth of residual stand

A. Gross volume per acre, board feet.--The residual volume per acre, by Scribner rule, of all trees that were 11.6 inches d.b.h. and larger at the beginning of the period of estimate.

B. Percent of volume in sugar pine and white fir.--The volume of sugar pine and white fir trees 11.6 inches d.b.h. and larger, expressed as a percentage of the volume of all trees 11.6 inches and larger.

C. Average volume per tree, board feet.--Volume of all trees 11.6 inches d.b.h. and larger, divided by the number of these trees.

D. Percent of volume in tree class 1.--Volume of trees 11.6 inches d.b.h. and larger that are in Dunning tree class 1, expressed as a percentage of volume in all trees 11.6 inches and larger.

G. Site index, feet.--The average total height, in feet, of mature dominant (Dunning tree class 3) trees in the stand (2).

X. Mean annual growth per acre, board feet.--Average annual growth per acre in board feet, Scribner rule, for a 20-year period, of all trees that were 11.6 inches d.b.h. and larger at the time of cutting.

Ingrowth from pole stand

A. Number of poles per acre.--Numbers of trees per acre, from 3.6 to 11.5 inches d.b.h., inclusive, at the beginning of the period of estimate. All species.

B. Percent of poles in sugar pine and white fir.--Number of sugar pine and white fir trees 3.6 to 11.5 inches d.b.h. expressed as a percentage of the number of trees of all species 3.6 to 11.5 inches d.b.h.

C. Percent of poles in tree class 1.--Number of trees 3.6 to 11.5 inches d.b.h. that are in Dunning tree class 1, expressed as a percentage of all trees 3.6 to 11.5 inches d.b.h.

D. Average diameter of pole stand, inches.--Average diameter of all trees 3.6 to 11.5 inches d.b.h. by basal area method. In application of the chart, the average of the diameters will be sufficiently accurate.

G. Site index, feet.--The average total height, in feet, of mature dominant trees (Dunning tree class 3) in the stand.

X. Average annual ingrowth per acre, board feet.--Volume by Scribner rule of the poles at the time they reach 11.6 inches d.b.h., plus subsequent growth, during a 20-year period.

Loss in residual stand

A. Gross volume per acre, board feet.--The volume per acre by Scribner rule of all trees that were 11.6 inches d.b.h. and larger at the beginning of the period of estimate.

C. Percent of volume in white fir.--Volume of white fir in trees 11.6 inches d.b.h. and larger expressed as a percentage of the volume of all species, trees 11.6 inches and larger.

D. Percent of volume in tree classes 4, 5, 6, and 7.--Volume of trees 11.6 inches d.b.h. and larger that are in Dunning tree classes 4 (mature codominant), 5 (overmature dominant), 6 (immature and intermediate or suppressed), and 7 (mature or overmature and intermediate or suppressed), expressed as percent of the volume in all trees 11.6 inches and larger.

G. Site index, feet.--The average total height, in feet, of mature dominant trees (Dunning tree class 3) in the stand.

X. Mean annual loss per acre, board feet.--Volume by Scribner rule of all trees 11.6 inches d.b.h. and larger that died during a 20-year period.

Analysis of Data

Growth of residual stand

Measurements of natural phenomena always show variation. The purpose of Clements' study was to find which measurable factors are correlated with variation of growth and loss and, in this way, to account for as much of the variation as possible. As greater amounts of variation are accounted for, greater confidence can be placed in the growth estimates.

Of the variables tested for linear correlation with gross growth, reserve volume accounted for the largest share of the total variation. The selected variables and the percent of variation explained by each were:

Reserve volume	22
Site index	18
Average volume per tree	15
Percent of volume in tree class 1	8
Percent of volume in sugar pine and white fir	6

Altogether, 69 percent of the variation was explained by multiple linear correlation. Curvilinear adjustments made in the process of developing the alinement charts accounted for an additional 10 percent of the variation. Therefore, the completed chart which estimates the annual gross growth of residual stands explains 79 percent of the total variation.

Growth increased as any independent variable increased, except "average volume per tree." As "average volume per tree" increased, growth decreased.

The standard error of estimate was 28 percent of the mean growth. This means that if 1-acre samples are used to estimate annual gross growth during a 20-year period after logging, 2 out of 3 estimates made with the alinement chart will be within 28 percent of the true mean.

Ingrowth from pole stand

The most important variable for predicting gross growth of the original pole stand was the number of poles per acre, which accounted for 24 percent of the variation of ingrowth. The other variables accounted for percents of variation as follows:

Site index	16
Percent of poles in sugar pine and white fir	10
Average diameter of pole stand	8
Percent of poles in tree class 1	6

Summing these percents shows that multiple linear correlation accounted for 64 percent of the total variation.

Considerable improvement was made by introducing curvilinearity into the alinement chart, the finished chart accounting for 82 percent of the variation. The standard error of estimate for 1-acre samples was 47 percent of the mean ingrowth.

Loss in residual stand

Results of the linear correlation concerned with loss in the residual stand showed that percents of variability were explained as follows:

Residual volume	8
Percent of volume in white fir	5
Percent of volume in tree classes 4, 5, 6, and 7	5
Site index	1

The total percent of variability explained by the measured variables aggregated only 19 percent. Therefore, the four independent variables combined accounted for only a minor part of the variation. The chart could not be improved by curvilinear relations because none were indicated.

The standard error of estimate was 140 percent of the mean loss. Historically, mortality data has always been extremely variable. For example, pure ponderosa pine stands in the Southwest had a mean periodic loss of 109 board feet with a standard deviation of 307 board feet, or 282 percent of the mean (4).

How to Use the Charts

The essential steps in estimating growth of a partially cut stand are:

1. Inventorying the timber.
2. Application of field data to growth and loss alinement charts.
3. Accumulation of annual growth for the 20-year period and addition to original volume to predict the net yield.

Sometimes several strata can be delineated within a residual stand so that attributes such as site, type, or amount of reserve volume will be homogeneous within a stratum. If the timbered area can be stratified before being inventoried, greater precision can be obtained in estimating stand data (5). Growth for the whole stand, determined by finding rates separately for each strata and then weighting on an area basis, will also be more accurate.

How to fit the intensity of the sample cruise to the requirements of a particular job has been discussed elsewhere. Briefly, a 1-percent cruise will give satisfactory limits of error for units of 10,000 acres or more. A cruise of this intensity should estimate total volume per acre within 10 percent of the true volume (3). Other required variables, such as average volume per tree, should be estimated within 15 percent by a 1-percent cruise. 2/

2/ Hasel, A. A. Sampling volume and other variables in cut-over stands in the California pine region. Calif. Forest and Range Exp. Sta. (Manuscript report). 44 pp. 1939.

Systematic sampling with a 1- by 2-chain plot (0.2 acre) in the center of each 10- by 20-chain block (20 acres) is recommended. If more intensive sampling is required either for greater accuracy or because units are smaller than 10,000 acres, longer plots may be used. Plots of 1 by 4 chains (0.4 acre) in the center of each 20 acres would be appropriate for a 2-percent cruise.

The following information should be recorded for each plot:

a. The number of trees 3.6 inches d.b.h. and larger tallied by 2-inch classes, species, and Dunning tree classes.

b. Site index expressed as the average total height, in feet, of mature dominant (class 3) trees on or adjacent to the plot. Incense-cedar should not be used in determining site index.

c. Total height, in feet, of 2 or 3 randomly selected trees on or near each plot. A height diameter curve for each species-site combination is needed in computing plot volume.

Next, values of the variables required for entering the aline-ment charts are calculated. 3/ To do this, the variables for all plots from a common site or type are first summed and then converted to a per-acre basis. Errors result if variables for each plot are first converted to a per-acre basis and then averaged.

3/ Most of the basic volume tables used in this study were published in: Munns, E. C. and R. M. Brown. Volume tables for the important timber trees of the United States, Part I, Western species. U. S. Dept. Agr., Forest Service. 159 pp. 1925.

The specific tables used are designated as:

Douglas-fir, Form 874 ss
Incense-cedar, Form 874 oo
Ponderosa pine, Form 874 qq
Sugar pine, Form 874 pp
White fir, Form 874 nn

Basic tables were interpolated to 1/10-inch diameter classes and 1-foot height classes. Greatest accuracy will be obtained from the Clements' charts when residual stand data are obtained from the interpolated volume tables. However, other accurate volume tables also will give acceptable estimates.

Loan copies of the interpolated tables are available from the California Forest and Range Experiment Station, P.O. Box 245, Berkeley 1, California.

Suppose we wish to estimate the gross annual growth of the stand 11.6 inches d.b.h. and larger, and the required variables have been computed as follows:

A.	Gross volume per acre, board feet	14,155
B.	Volume in sugar pine and white fir, percent	91
D.	Volume in tree class 1, percent	50
G.	Site index, feet	200
C.	Average volume per tree, board feet	450

Using the gross growth chart (fig. 1), we first find 14,155 board feet on the A scale, and hold this point with a needle. Next we find and hold 91 percent on the B scale with a second needle. A true straightedge is carefully pushed against the needles, and the point where straightedge and S_1 axis intersect is held with one of the needles. The other needle is then used to mark 50 percent on the D scale, and again the straightedge is placed carefully against the needles. This time the intersection of the straightedge and the S_2 axis is held. The G scale is then marked at 200 feet and held. The straightedge is again moved. The point on S_3 which is alined with the S_2 intercept and with site index 200 is found and marked. The straightedge is finally laid from the S_3 point to 450 board feet on the C scale. The point where the straightedge crosses the X axis gives the estimated annual gross growth--in this case 620 board feet.

The charts to predict ingrowth (fig. 2) and loss (fig. 3) are used in the same manner. Users of the charts are cautioned always to enter each chart in the order shown in the key.

If variables for the pole stand are:

A.	Poles per acre, number	67
B.	Poles in sugar pine and white fir, percent	81
C.	Poles in tree class 1, percent	27
D.	Average diameter of pole stand, inches . . .	7
G.	Site index, feet	200

Then:

X.	Annual ingrowth from original pole stand should be estimated as	179 bd. ft.

When the variables for predicting annual loss are:

A.	Volume per acre, board feet	14,155
C.	Volume in white fir, percent	53
D.	Volume classes 4, 5, 6, and 7, percent	27
G.	Site index, feet	200

Then:

X.	Estimated annual loss is predicted as	143 bd. ft.

The procedure used to obtain the final yield in board feet per acre 20 years after logging is outlined below:

		Board feet
1.	From the gross annual growth of the residual stand	620
2.	Subtract the annual loss	143
3.	Add the annual ingrowth	179
	The annual net growth per acre is	656
4.	Multiply the annual net growth by the period of prediction . . . . . 656 x 20 =	13,120
5.	Add the original volume per acre	14,155
	Yield per acre 20 years after logging is	27,275

Accuracy of Estimates

The correlation of growth and loss with selected stand attributes can explain only part of the variation of estimates for two reasons. First, variables of minor importance were not used. Although additional attributes might explain small increments of remaining variation, the law of diminishing returns operates here. Every additional stand measurement makes the development and use of an alinement chart more unwieldy. Secondly, many purely local environmental conditions cannot be measured even though they definitely influence stand growth or loss. For example, a plot being sampled may have deeper soil than the surrounding stand or irregularities in topography may cause temperature or precipitation differences which are unknown to the forester. Therefore, some variation in the estimates remains unexplained.

The standard error of estimate for predicted net annual growth is 156.1 board feet, or 73 percent of the actual net rate of 214 board feet per acre as the following tabulation shows:

Statistic	Standard Error of Estimate	
	Volume (board feet)	Proportion of mean (percent)
Growth - residual stand	70.4	28
Ingrowth - pole stand	22.2	47
Loss - residual stand	119.6	140
Net annual growth	156.1	73
Yield 20 years after cutting	3,121.2	14

This large standard error is mainly the result of extreme variability in tree mortality. However, the ultimate use of growth prediction is to estimate the final volume of partially cut stands at a future date. This can be done with a standard error of estimate of 3,121 board feet, or 14 percent of the actual mean yield of 22,246 board feet, for the 20-year period. Such a small error may be surprising in light of the high residual errors in some of the steps. However, the error of 156 board feet per acre per year is small compared to the reserve stand of nearly 18,000 board feet per acre.

The standard errors of estimate listed above measure the accuracy of the alinement charts in predicting 20-year yields for 1-acre samples. Large standard errors do not mean the alinement charts are inaccurate. Actually, errors for individual plots are compensating. The standard errors do mean that the variation of actual from estimated values is rather large for individual plots only 1-acre in size.

In actual application to forest management such small samples would never be used. If a 10,000 acre unit has 1 percent of its area sampled, a standard error of estimate only one-tenth that of 1-acre samples, or about 1.5 percent would be expected. For the same degree of accuracy, a 1,000 acre unit would require a 10-percent sample. In both cases the total sample size would be 100 acres. Note that the error (1.5 percent) inherent in the alinement charts for this intensity of sampling is much less than the errors associated with estimates of residual stand variables (10 to 15 percent).

In using the charts remember that they were prepared under the assumption that the residual timber would be inventoried immediately after logging. If inventories are made later the possibility for additional errors must be recognized.

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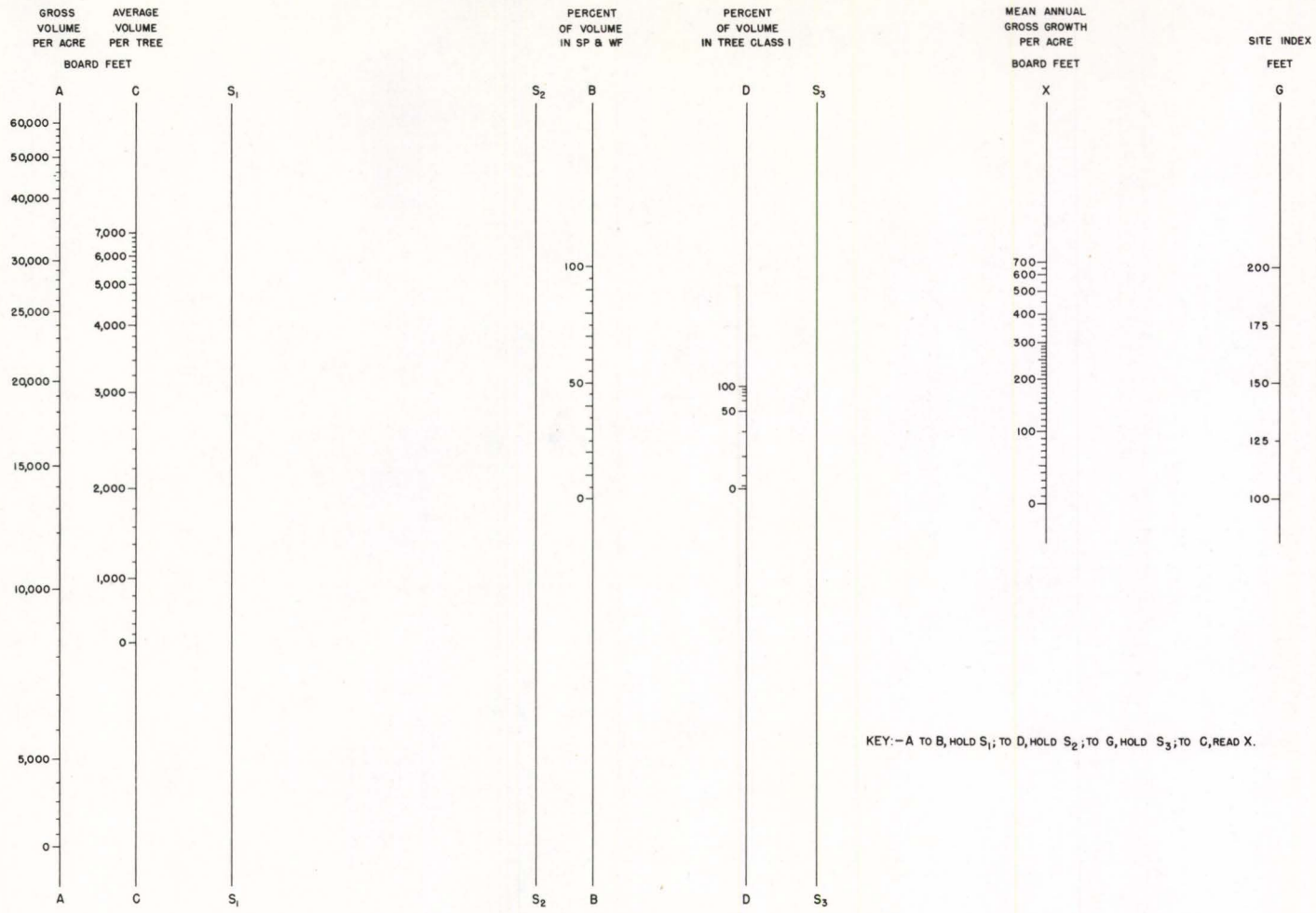

FIGURE 1 - CHART FOR ESTIMATION OF

GROSS GROWTH

IN RESIDUAL FORESTS OF THE SIERRA NEVADA

STAND 11.6 INCHES DBH AND OVER

SCRIBNER RULE

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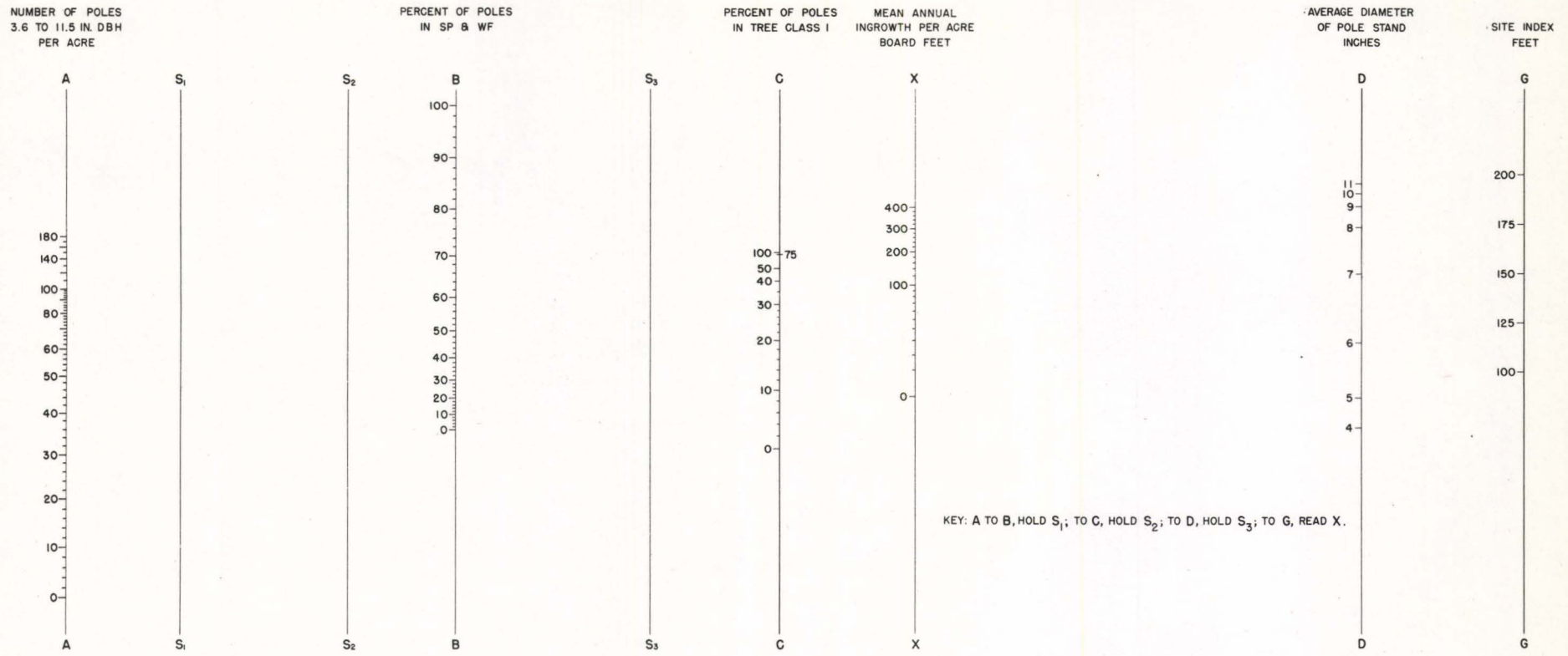

FIGURE 2 - CHART FOR ESTIMATION OF

INGROWTH

IN RESIDUAL FORESTS OF THE SIERRA NEVADA

TREES GROWING INTO THE STAND 11.6 INCHES DBH AND OVER

SCRIBNER RULE

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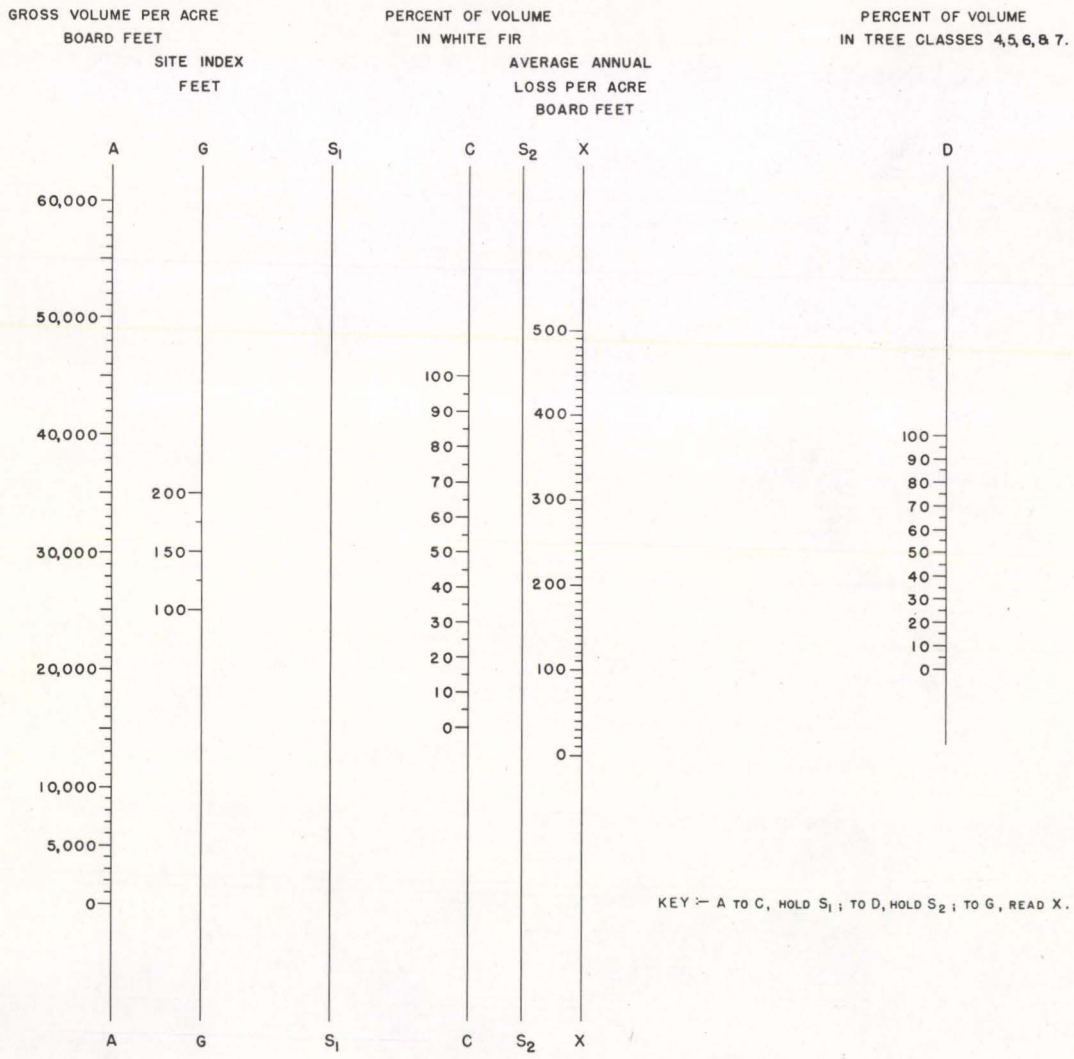

FIGURE 3 - CHART FOR ESTIMATION OF

LOSS

IN RESIDUAL FORESTS OF THE SIERRA NEVADA

STAND 11.6 INCHES DBH AND OVER

SCRIBNER RULE

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